

Abstract Title: Utilizing the ISS Mission as a Testbed to Develop Cognitive Communications Systems

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The ISS provides an excellent opportunity for pioneering artificial intelligence software to meet the challenges of real-time communications (comm) link management. This opportunity empowers the ISS Program to forge a testbed for developing cognitive communications systems for the benefit of the ISS mission, manned Low Earth Orbit (LEO) science programs and future planetary exploration programs.

In November, 1998, the Flight Operations Directorate (FOD) started the ISS Antenna Manager (IAM) project to develop a single processor supporting multiple comm satellite tracking for two different antenna systems. Further, the processor was developed to be highly adaptable as it supported the ISS mission through all assembly stages. The ISS mission mandated communications specialists with complete knowledge of when the ISS was about to lose or gain comm link service. The current specialty mandated cognizance of large sun-tracking solar arrays and thermal management panels in addition to the highly-dynamic satellite service schedules and rise/set tables. This mission requirement makes the ISS the ideal communications management analogue for future LEO space station and long-duration planetary exploration missions. Future missions, with their precision-pointed, dynamic, laser-based comm links, require complete autonomy for managing high-data rate communications systems. Development of cognitive communications management systems that permit any crew member or payload science specialist, regardless of experience level, to control communications is one of the greater benefits the ISS can offer new space exploration programs.

The IAM project met a new mission requirement never previously levied against US space-born communications systems management: process and display the orientation of large solar arrays and thermal control panels based on real-time joint angle telemetry. However, IAM leaves the actual communications availability assessment to human judgement, which introduces unwanted variability because each specialist has a different core of experience with comm link performance. Because the ISS utilizes two different frequency bands, dynamic structure can be occasionally translucent at one frequency while it can completely interdict service at the other frequency. The impact of articulating structure on the comm link can depend on its orientation at the time it impinges on the link. It can become easy for a human specialist to cross-associate experience at one frequency with experience at the other frequency. Additionally, the specialist's experience is incremental, occurring one nine-hour shift at a time. Only the IAM processor experiences the complete 24x7x365 communications link performance for both communications links but, it has no "learning capability." If the IAM processor could be endowed with a cognitive ability to remember past structure-induced comm link outages, based on its knowledge of the ISS position, attitude, communications gear, array joint angles and tracking accuracy, it could convey such experience to the human operator. It could also use its learned communications link behaviors to accurately convey the availability of future communications sessions. Further, the tool could remember how

accurately or inaccurately it predicted availability and correct future predictions based on past performance. The IAM tool could learn frequency-specific impacts due to spacecraft structures and pass that information along as “experience.” Such development would provide a single artificial intelligence processor that could provide two different experience bases. If it also “knew” the satellite service schedule, it could distinguish structure blockage from schedule or planet blockage and then quickly switch to another satellite. Alternatively, just as a human operator could judge, a cognizant comm system based on the IAM model could “know” that the blockage is not going to last very long and continue tracking a comm satellite, waiting for it to track away from structure. Ultimately, once this capability was fully developed and tested in the Mission Control Center, it could be transferred on-orbit to support development of operations concepts that include more advanced cognitive communications systems.

Future applications of this capability are easily foreseen because even more dynamic satellite constellations with more nodes and greater capability are coming. Currently, the ISS fully employs its high-data-rate return link for harvesting payload science. In the coming months, it will double that data rate and is forecast to fully utilize that capability. Already there is talk of an upgrade that quadruples the current data rate allocated to ISS payload science before the end of its mission and laser comm links have already been tested from the ISS. Every data rate upgrade mandates more complicated and sensitive communications equipment which implies greater expertise invested in the human operator. Future on-orbit cognizant comm systems will be needed to meet greater performance demands aboard larger, far more complicated spacecraft. In the LEO environment, the old-style one-satellite-per-spacecraft operations concept will give way to a new concept of a single customer spacecraft simultaneously using multiple comm satellites. Much more highly-dynamic manned LEO missions with decades of crew members potentially increase the demand for communications link performance. A cognizant on-board communications system will meet advanced communications demands from future LEO missions and future planetary missions.

The ISS has fledgling components of future exploration programs, both LEO and planetary. Further, the Flight Operations Directorate, through the IAM project, has already begun to develop a communications management system that attempts to solve advanced problems ideally represented by dynamic structure impacting scheduled satellite service. With an earnest project to integrate artificial intelligence into the IAM processor, the ISS Program could develop a cognizant communications system that could be adapted and transferred to future on-orbit avionics designs.

Short Abstract:

The ISS Program offers an outstanding opportunity to testbed cognizant communications systems concepts for future space exploration programs. An existing tool, the ISS Antenna Manager, provides a foundational basis in which to integrate artificial intelligence software to begin real-time development and testing for on-board communications systems management.

Utilizing the ISS Mission as a Testbed to Develop Cognitive Communications Systems



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Overview

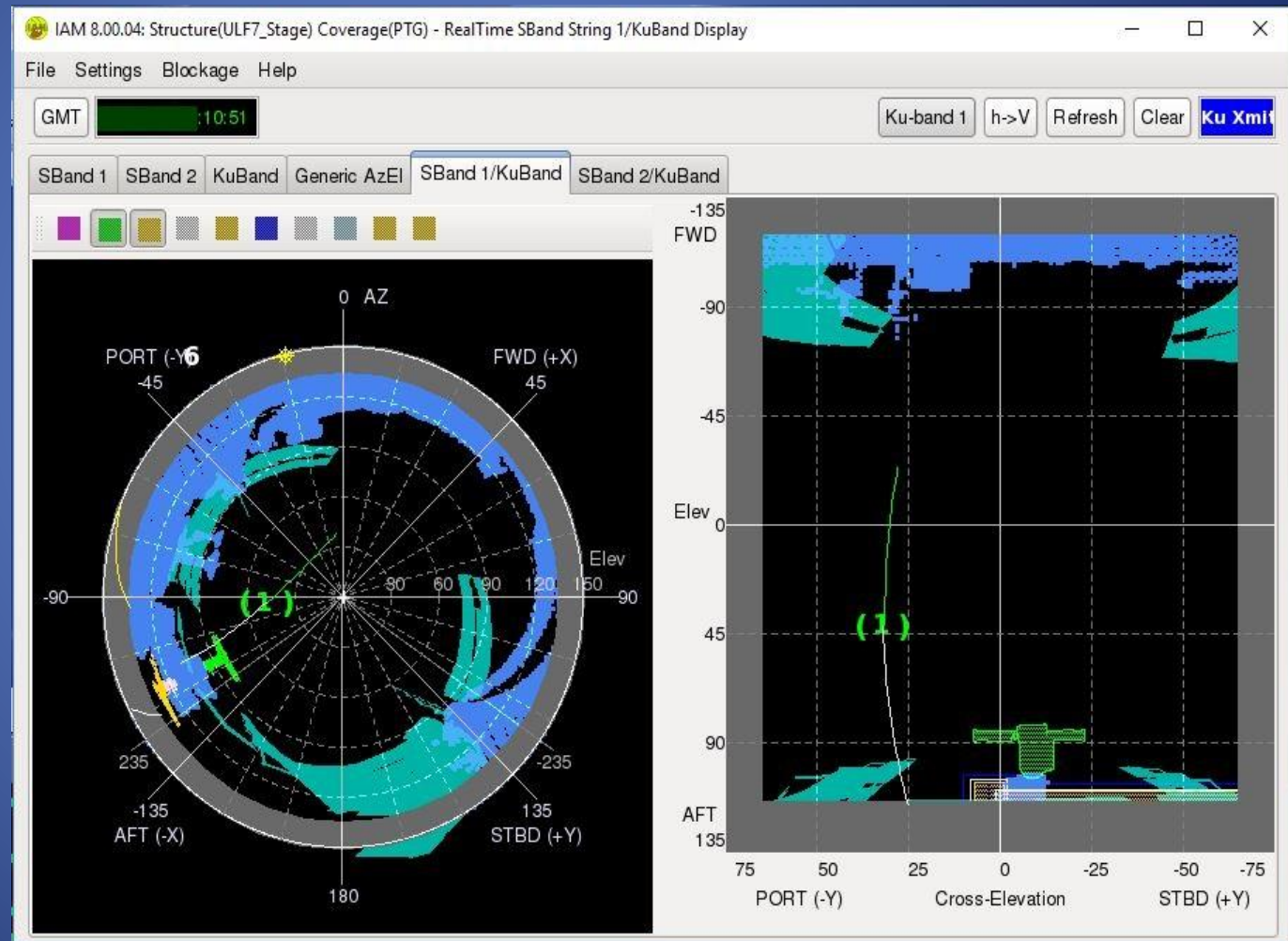
- Purpose
- Foundational development: the ISS Antenna Manager (IAM)
- What the future demands
- Proposed cognitive communications systems projects that could be developed at JSC
- Conclusion – a good investment in time and resource for future development.

Purpose

- Identify elements of future space communications systems that justify using the ISS as a development testbed for autonomous comm management systems.
- Propose artificial intelligence development projects at JSC to pioneer and test elements of cognizant communications management systems.

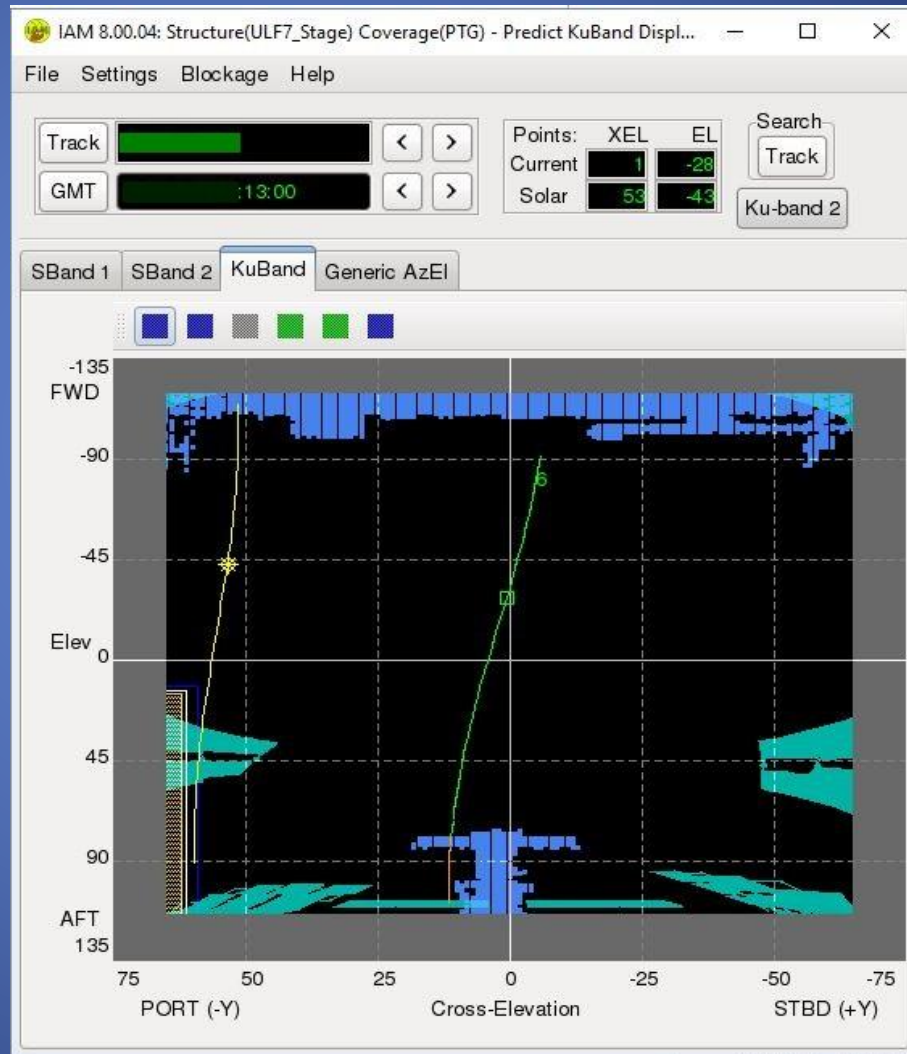
Foundational Development: the ISS Antenna Manager – Realtime Display

- Provides realtime TDRS tracking information in both S-band and Ku-band coordinates.
- Provides a graphical depiction of the ISS structure in both antenna coordinates.
- Displays sun tracking data.



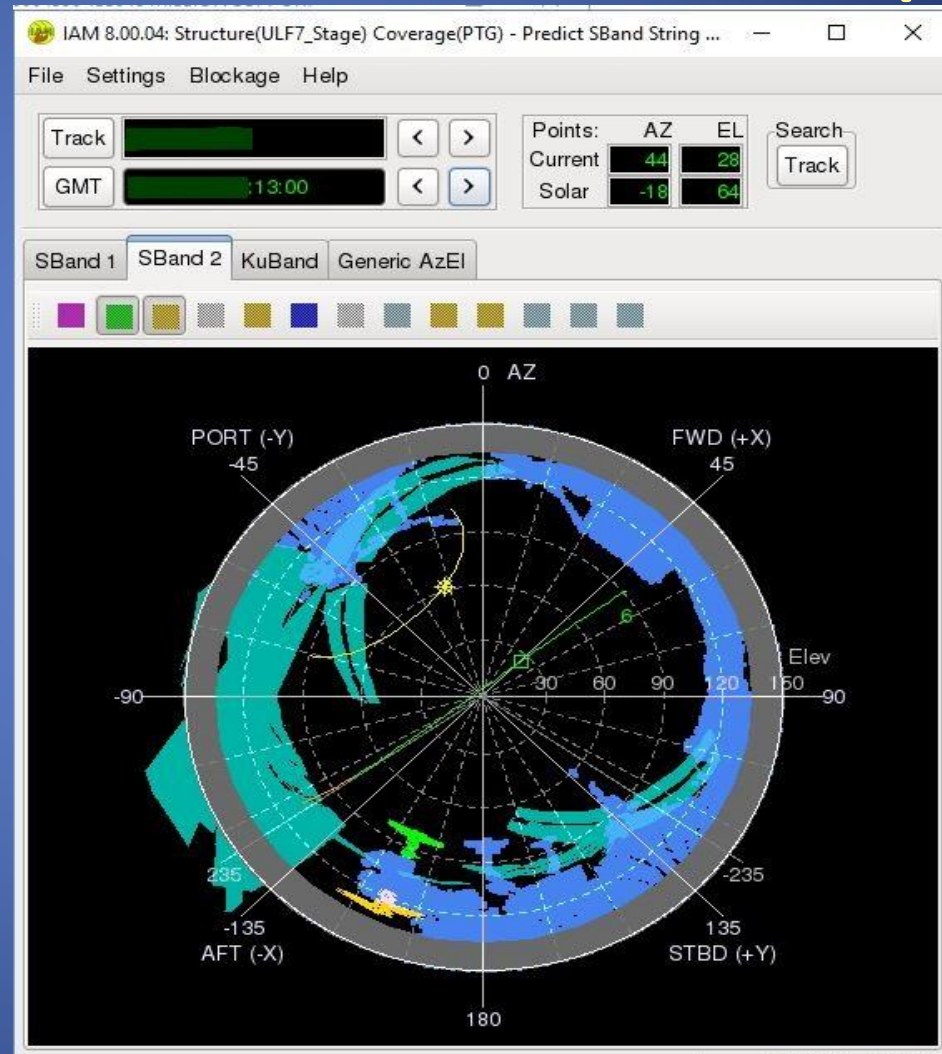
Foundational Development: the ISS Antenna Manager – Ku-Band Predict Display

- Graphically represents predictions of satellite location, sun position and solar array orientation.
- Empowers the humans to assess comm availability for future operations – up to seven days in advance.
- Provides sun and satellite location in antenna coordinates for two different Ku-band antennas.



Foundational Development: the ISS Antenna Manager – S-Band Predict Display

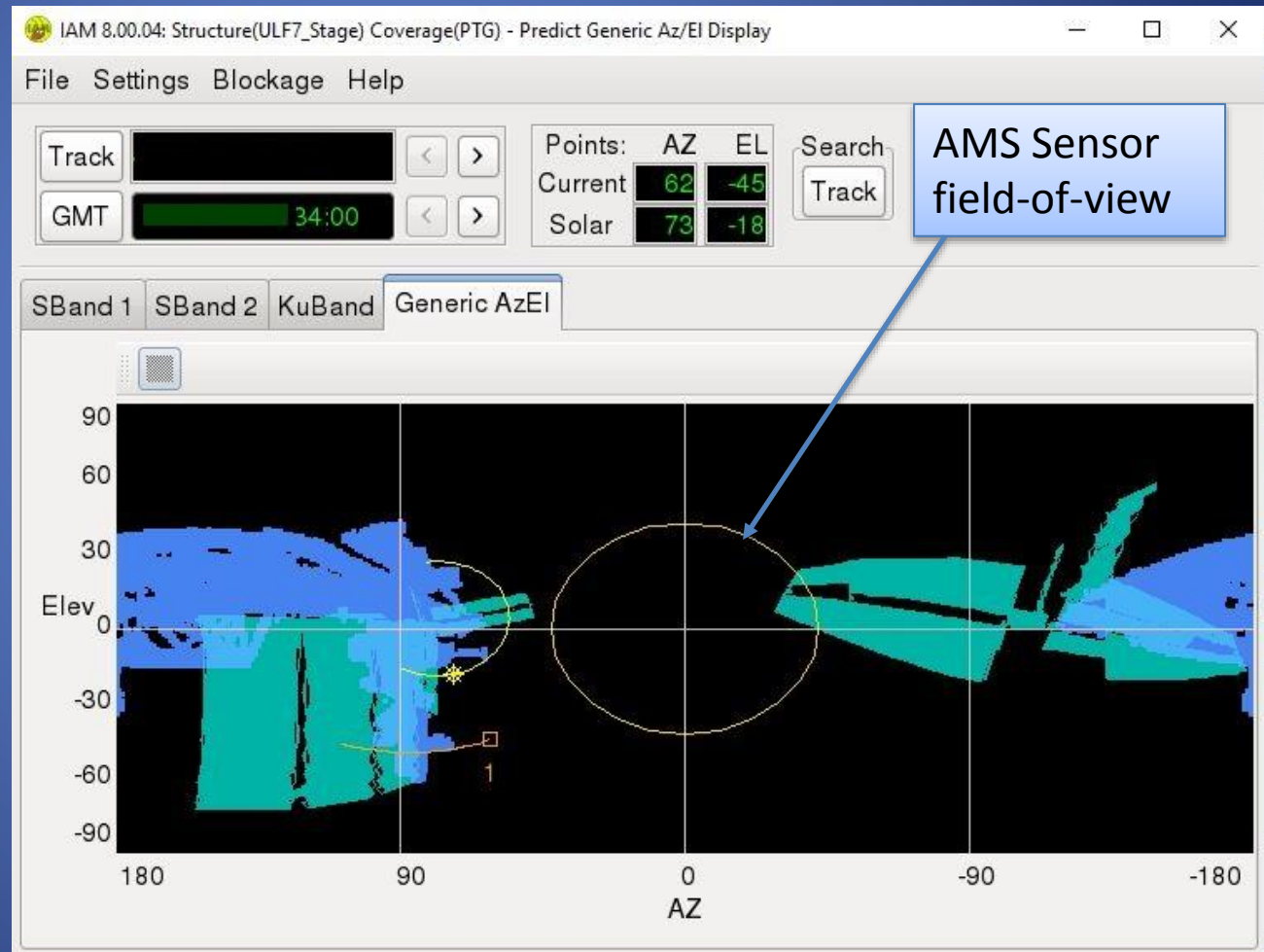
- Supports points of view from both S-band #1 and S-band #2 location.
- As with Ku-band, empowers comm availability assessment for future operations.
- Provides sun and satellite location in S-band antenna coordinates.



Foundational Development: the ISS

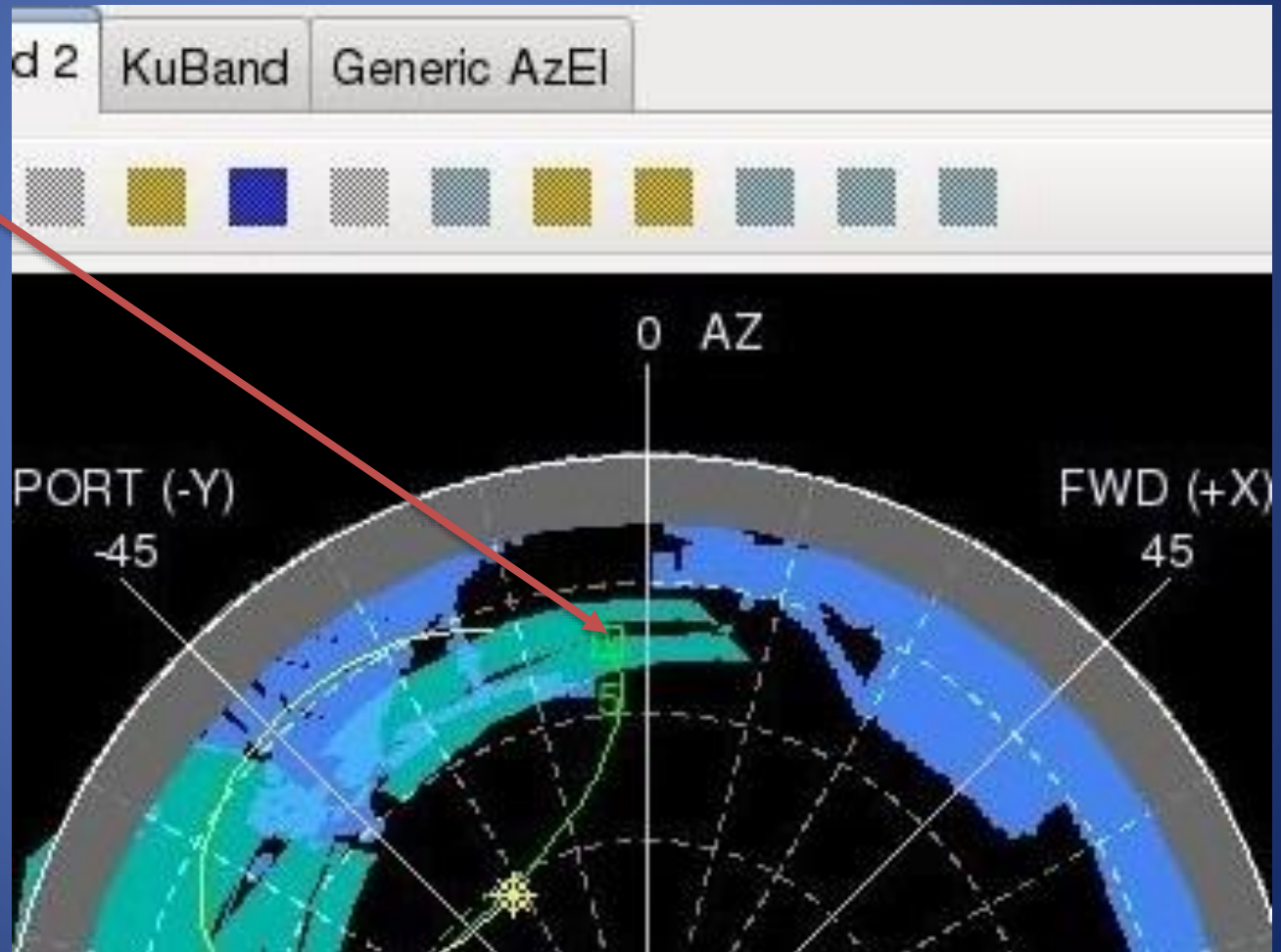
Antenna Manager – Generic Predict Display

- Supports points of view for any ISS sensor: AMS is the example, here.
- Permits AMS (or any sensor) to look ahead and assess comm availability during any sensor operation of concern.
- Provides sun and satellite location in generic sensor coordinates.
- Supports commercial visiting vehicles' fields of view, also.



Foundational Development: Human Experience Accumulates with IAM

- An event like this represents an example of human variability.
- Some flight controllers remember comm being available during events like these.
- Others would never forecast available comm during events like these.
- Human experience causes variability in comm calls.



Foundational Development: Crew Sees a Mathematical Representation of Comm Availability

- In the on-orbit plan, the crew is informed when the comm links are geometrically blocked without regard for comm link performance margin.
- This mathematical assessment is a conservative estimate that never modifies based on how accurately availability was predicted.



This illustration is a screen shot of the crew's view of the plan – to include comm availability.

Color Key:

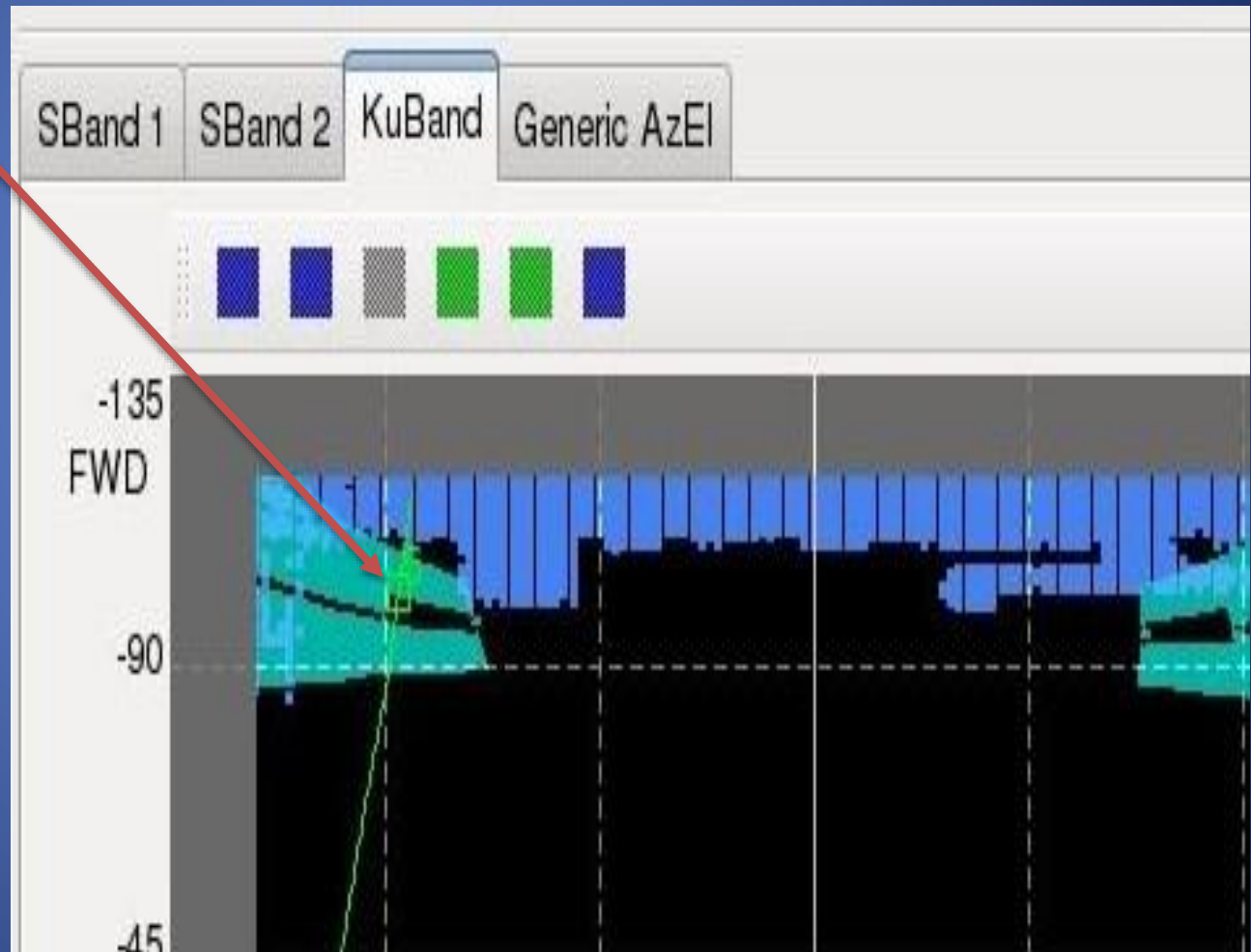
Orange: Ku-band availability

Green: S-band availability

Gaps in the color bars indicate structure blockage or scheduled outages.

Foundational Development: Human Flight Controller Experience Accumulates with IAM

- Ku-band offers predictive challenges similar to S-band but with different performance characteristics.
- IAM offers the flight controller the opportunity to develop interpretive experience regarding communications links.



Foundational Development: Human Flight Controller Experience Accumulates with IAM

- Standard computer hardware and software, with their digital approximations for an analog Universe, do not easily provide a synthetic interpretation of communications link performance.
 - ISS presents a multitude of variables that would require a host of indices into a database when the computer is expected to “remember” what happened during comm passes with similar geometries:
 - Two solar array rotary joint (SARJ) angles, eight beta gimbal angles and two thermal radiator rotary joints for tracking the sun
 - S-band and Ku-band frequencies offer different reflective/interference patterns and involve different comm link performance margins.
 - Comm hardware performance degrades either gradually or unexpectedly.
 - Current computers are not easily programmed to learn from their mistakes in predictions.
- For these reasons, current crews see computer-generated plans that never evolve with factors based on real-world experience in comm systems performance.
 - Ku-band availability indicators in the crew’s on-board plan have been wrong by 1-3 minutes for more than a decade.

What the Future Demands

- RF spectrum allocations chart from the National Telecommunications and Information Administration (January, 2016).
- The RF spectrum is crowded – demanding higher frequency band allocations for space exploration.

VHF – 30 – 300 MHz

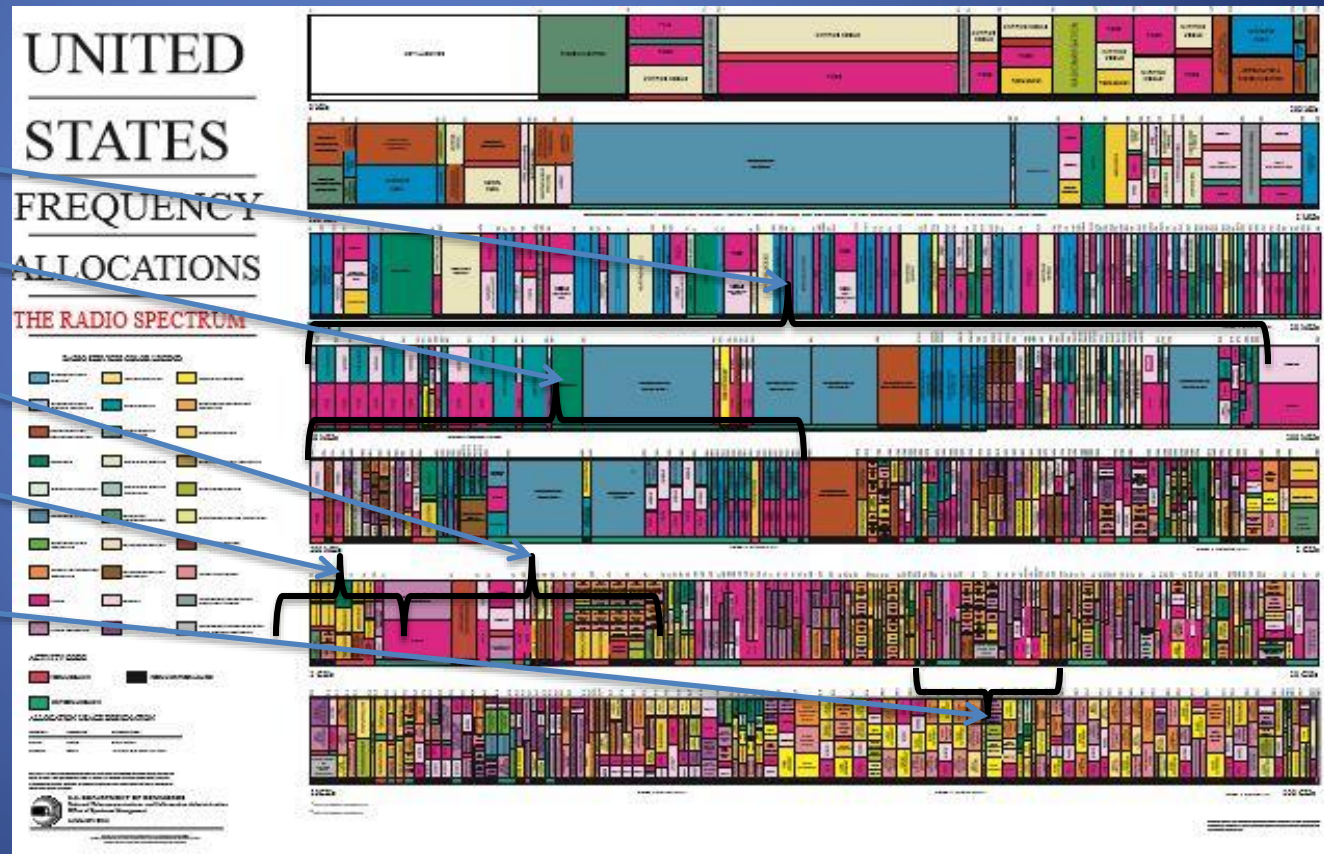
UHF: 300 MHz – 1 GHz

C-band – 4-8 GHz

S-band – 2-4 GHz

Ku-band – 12-18 GHz

**Baseband – the
modulating signal
with the information
we want to convey.**



What the Future Demands

- Hi-capacity basebands for both Low-Earth Orbit (LEO) and interplanetary exploration.
 - ISS six-person crew provides representative metrics for baseband expectations.
 - On-board local-area-network (LAN) connects to support internet connections for file/photo transfers and e-mail.
 - Six video channels and roughly 100 payload data channels are utilized near-capacity all the time.
 - Four audio channels support day-to-day operations as well as payload science.
 - Video supports medical conferences, family conferences and experiments sponsored by universities in real-time.
 - Based on the realtime experience with ISS, the program will double its baseband capacity in 2017.

What the Future Demands

- Higher carrier frequencies to support larger basebands.
 - Higher carrier frequencies increase the effective gain of a fixed-size parabolic dish antenna.
 - An advantage that indicates smaller antennas are possible.
 - Laser comm links actually allow for telescopes.
 - Higher carrier frequencies decrease the beamwidth utilized by the transmitter and receiver -- a potential challenge for pointing/tracking systems.
- Higher performance standards for transmitters and receivers.
 - Greater distances mandate bigger transmitters along with broader bandwidth.
 - Receivers with lower system noise figures and broader bandwidth.

What the Future Demands

- The future demands laser communications to support higher-capacity basebands.
 - They support higher baseband data rates with smaller bit error rates.
 - Tighter beams deliver more carrier power to distant receivers thereby supporting greater distances between transmitters and receivers.
 - Narrower beams support more secure data paths.
 - Microwave links use beamwidths on the order of 1°
 - Laser links can use beamwidths on the order of 0.00029° .
- Future communications systems require increased expertise that will be instilled in the systems hardware and software – not in human crew members.

What the Future Demands

- Future microwave and laser communications demand “cognizant” communications systems.
 - A communications system that is aware of all the elements necessary to maintain a continuously reliable communications link
 - An expert communications system that can target communications satellites without attention from crew members
 - An autonomous system that can resolve communications problems, including systems failures – redundancy with durable components
 - A precision system that provides more accurate antenna and telescope pointing for tracking communications satellites
 - A comm system that self-corrects its performance, based on how well it performed during previous satellite comm sessions

Proposed cognitive communications systems projects that could be developed at JSC

- The ISS Antenna Manager provides an outstanding testbed for the development of a cognizant communications system.
 - Use IAM as a testbed to develop a kernel of artificial intelligence that could be transferred to future spacecraft for communications management.
 - The ISS utilizes two completely different communications links to support Ops:

S-band for
real-time
systems
command
and control



Ku-band for
real-time
video and
payload
science



Proposed cognitive communications systems projects that could be developed at JSC

- The ISS Antenna Manager provides an outstanding testbed...(continued).
 - Two S-band antennas located along the main truss in port and starboard locations.
 - Two Ku-band antennas located very near the ISS center-of-mass but with sufficiently different points-of-view to provide different comm availability characteristics.
 - For the purpose of developing artificial intelligence that provides autonomous decision making, the ISS offers four different antenna systems operating in two different frequency bands.

Proposed cognitive communications systems projects that could be developed at JSC

- The ISS Antenna Manager provides an outstanding testbed...(continued).
 - Such a configuration of diverse communications equipment provides an excellent real-world testbed of opportunity for developing a decision-making machine aimed at autonomous communications system management
 - Different comm link blockage situations
 - Different operating frequencies
 - Different performance characteristics

Proposed cognitive communications systems projects that could be developed at JSC

- Many benefits from starting an artificial intelligence project using the ISS Antenna Manager:

Project	Benefit to Future Systems	Benefit to the ISS Program
Develop “IAM Should Remember”: uses past comm link experience to indicate comm service availability during current passes.	Pioneers a synthetic “experience accumulator” without large data storage requirements to be applied to advanced, autonomous communications systems.	Standardizes real-time “comm calls” regarding availability during structure blockage impinging on comm links. (Modifies the display to indicate structural impact on the comm link.)
Develop comm satellite tracker inside of IAM. (Includes attitude, attitude rate, position and velocity knowledge)	Stepping-stone development of a comm management system that is cognizant of its comm resources. (Incorporates vehicle body rates into tracking computations.)	Minimizes IAM’s dependence on the ISS’s guidance, navigation and control (GNC) computer’s TDRS tracking.

Proposed cognitive communications systems projects that could be developed at JSC

- Many benefits from starting an artificial intelligence project...(continued):

Project	Benefit to Future Systems	Benefit to the ISS Program
Develop an ISS tracker in IAM. (Propagates state as measured by GPS and re-checks propagation against actual GPS measurements.)	Stepping-stone development toward a comm management system that is cognizant of its place in the Universe.	<p>Improves IAM's support of emergency situations demanding a real-time change in TDRS support. (Loss of attitude control while maintaining attitude knowledge completely changes comm satellite line-of-sight.)</p> <p>Develops an IAM that could schedule its own TDRS satellites based on IAM's experience with S-band and Ku-band performance.</p>

Proposed cognitive communications systems projects that could be developed at JSC

- Many benefits from starting an artificial intelligence project...(continued):

Project	Benefit to Future Systems	Benefit to the ISS Program
Integrate “System Pointing Performance” into IAM.	Stepping-stone development toward a comm management system that is aware of how accurately it tracks comm satellites.	Improves IAM’s forecasting accuracy of TDRS/service availability during realtime operations. Display indicates uncertainty on comm satellite position.
System Pointing Performance, an existing console tool, constantly evaluates the GNC tracking against the Ku-band auto-tracking to develop a measurement of pointing accuracy.	Stepping-stone development toward a comm management system that self-corrects based on past errors.	Mandates technical effort toward improving pointing performance to support higher data rates.

Proposed cognitive communications systems projects that could be developed at JSC

- Many benefits from starting an artificial intelligence project...(continued):

Project	Benefit to Future Systems	Benefit to the ISS Program
Develop a 3-D graphical user interface (GUI) for IAM.	<p>Provides future crew members a “situation-at-a-glance” interpretation of the comm link.</p> <p>Pioneers/evaluates an alternate synthetic evaluation of the comm link: whether to use the graphics to interpret performance as a human would or whether to stick with mathematical/ geometric interpretation.</p>	<p>Modernizes IAM for 21st century Ops.</p> <p>Minimizes specialization and simplifies training by depicting the Universe in 3-D, as humans understand it, rather than in antenna coordinates, which are foreign to non-comm specialists.</p>

Conclusion

- Future demands for higher-precision, higher-reliability and autonomous communications systems justify using the ISS as a testbed for the development of a cognizant communications management system.
- Because of the command and control problems related to comm systems management during ISS assembly, the ISS Antenna Manager, which supported assembly, is an outstanding testbed for integrating artificial intelligence into on-orbit communications systems of the future.